
IMAGE and VIDEO
COMPRESSION
for MULTIMEDIA
ENGINEERING

Fundamentals,
Algorithms, and Standards

Yun Q. Shi
Huifang Sun

Contents

Section I Fundamentals

Chapter 1 Introduction

1.1	Practical Needs for Image and Video Compression.....	4
1.2	Feasibility of Image and Video Compression	4
1.2.1	Statistical Redundancy	4
1.2.2	Psychovisual Redundancy.....	9
1.3	Visual Quality Measurement	18
1.3.1	Subjective Quality Measurement.....	19
1.3.2	Objective Quality Measurement	20
1.4	Information Theory Results	24
1.4.1	Entropy	24
1.4.2	Shannon's Noiseless Source Coding Theorem.....	25
1.4.3	Shannon's Noisy Channel Coding Theorem	26
1.4.4	Shannon's Source Coding Theorem	27
1.4.5	Information Transmission Theorem.....	27
1.5	Summary	27
1.6	Exercises.....	28
	References	28

Chapter 2 Quantization

2.1	Quantization and the Source Encoder	31
2.2	Uniform Quantization	33
2.2.1	Basics	33
2.2.2	Optimum Uniform Quantizer.....	37
2.3	Nonuniform Quantization	40
2.3.1	Optimum (Nonuniform) Quantization	42
2.3.2	Companding Quantization	43
2.4	Adaptive Quantization	45
2.4.1	Forward Adaptive Quantization	47
2.4.2	Backward Adaptive Quantization	48
2.4.3	Adaptive Quantization with a One-Word Memory	48
2.4.4	Switched Quantization	48
2.5	PCM	49
2.6	Summary	50
2.7	Exercises.....	52
	References	52

Chapter 3 Differential Coding

3.1	Introduction to DPCM	55
3.1.1	Simple Pixel-to-Pixel DPCM.....	55
3.1.2	General DPCM Systems	58
3.2	Optimum Linear Prediction	60

3.2.1	Formulation	60
3.2.2	Orthogonality Condition and Minimum Mean Square Error.....	61
3.2.3	Solution to Yule-Walker Equations.....	62
3.3	Some Issues in the Implementation of DPCM.....	62
3.3.1	Optimum DPCM System.....	62
3.3.2	1-D, 2-D, and 3-D DPCM.....	63
3.3.3	Order of Predictor.....	64
3.3.4	Adaptive Prediction.....	64
3.3.5	Effect of Transmission Errors.....	65
3.4	Delta Modulation.....	65
3.5	Interframe Differential Coding.....	68
3.5.1	Conditional Replenishment.....	68
3.5.2	3-D DPCM.....	69
3.5.3	Motion-Compensated Predictive Coding.....	71
3.6	Information-Preserving Differential Coding.....	71
3.7	Summary.....	72
3.8	Exercises.....	73
	References.....	73

Chapter 4 Transform Coding

4.1	Introduction.....	75
4.1.1	Hotelling Transform.....	75
4.1.2	Statistical Interpretation.....	77
4.1.3	Geometrical Interpretation.....	78
4.1.4	Basis Vector Interpretation.....	79
4.1.5	Procedures of Transform Coding.....	80
4.2	Linear Transforms.....	80
4.2.1	2-D Image Transformation Kernel.....	80
4.2.2	Basis Image Interpretation.....	83
4.2.3	Subimage Size Selection.....	84
4.3	Transforms of Particular Interest.....	84
4.3.1	Discrete Fourier Transform (DFT).....	85
4.3.2	Discrete Walsh Transform (DWT).....	86
4.3.3	Discrete Hadamard Transform (DHT).....	87
4.3.4	Discrete Cosine Transform (DCT).....	88
4.3.5	Performance Comparison.....	92
4.4	Bit Allocation.....	95
4.4.1	Zonal Coding.....	95
4.4.2	Threshold Coding.....	96
4.5	Some Issues.....	102
4.5.1	Effect of Transmission Errors.....	102
4.5.2	Reconstruction Error Sources.....	102
4.5.3	Comparison Between DPCM and TC.....	103
4.5.4	Hybrid Coding.....	103
4.6	Summary.....	103
4.7	Exercises.....	105
	References.....	106

Chapter 5 Variable-Length Coding: Information Theory Results (II)

5.1	Some Fundamental Results.....	107
-----	-------------------------------	-----

5.1.1	Coding an Information Source	107
5.1.2	Some Desired Characteristics	108
5.1.3	Discrete Memoryless Sources.....	111
5.1.4	Extensions of a Discrete Memoryless Source.....	112
5.2	Huffman Codes	114
5.2.1	Required Rules for Optimum Instantaneous Codes.....	114
5.2.2	Huffman Coding Algorithm.....	115
5.3	Modified Huffman Codes	117
5.3.1	Motivation	117
5.3.2	Algorithm	118
5.3.3	Codebook Memory Requirement	118
5.3.4	Bounds on Average Codeword Length.....	119
5.4	Arithmetic Codes	119
5.4.1	Limitations of Huffman Coding	120
5.4.2	Principle of Arithmetic Coding	120
5.4.3	Implementation Issues.....	125
5.4.4	History	126
5.4.5	Applications	127
5.5	Summary	127
5.6	Exercises.....	128
	References	129

Chapter 6 Run-Length and Dictionary Coding: Information Theory Results (III)

6.1	Markov Source Model	131
6.1.1	Discrete Markov Source	131
6.1.2	Extensions of a Discrete Markov Source.....	133
6.1.3	Autoregressive (AR) Model.....	133
6.2	Run-Length Coding (RLC).....	134
6.2.1	1-D Run-Length Coding	134
6.2.2	2-D Run-Length Coding	135
6.2.3	Effect of Transmission Error and Uncompressed Mode.....	138
6.3	Digital Facsimile Coding Standards	139
6.4	Dictionary Coding.....	140
6.4.1	Formulation of Dictionary Coding	140
6.4.2	Categorization of Dictionary-Based Coding Techniques.....	140
6.4.3	Parsing Strategy	141
6.4.4	Sliding Window (LZ77) Algorithms.....	142
6.4.5	LZ78 Algorithms.....	145
6.5	International Standards for Lossless Still Image Compression	149
6.5.1	Lossless Bilevel Still Image Compression	150
6.5.2	Lossless Multilevel Still Image Compression	150
6.6	Summary	151
6.7	Exercises.....	152
	References	153

Section II Still Image Compression

Chapter 7 Still Image Coding Standard: JPEG

7.1	Introduction	157
7.2	Sequential DCT-Based Encoding Algorithm.....	159

7.3	Progressive DCT-Based Encoding Algorithm	163
7.4	Lossless Coding Mode.....	164
7.5	Hierarchical Coding Mode.....	166
7.6	Summary	167
7.7	Exercises.....	167
	References	167

Chapter 8 Wavelet Transform for Image Coding

8.1	Review of the Wavelet Transform	169
8.1.1	Definition and Comparison with Short-Time Fourier Transform	169
8.1.2	Discrete Wavelet Transform	172
8.2	Digital Wavelet Transform for Image Compression	174
8.2.1	Basic Concept of Image Wavelet Transform Coding.....	174
8.2.2	Embedded Image Wavelet Transform Coding Algorithms.....	176
8.3	Wavelet Transform for JPEG-2000.....	179
8.3.1	Introduction of JPEG-2000	179
8.3.2	Verification Model of JPEG-2000.....	180
8.4	Summary	182
8.5	Exercises.....	182
	References	183

Chapter 9 Nonstandard Image Coding

9.1	Introduction	185
9.2	Vector Quantization.....	186
9.2.1	Basic Principle of Vector Quantization.....	186
9.2.2	Several Image Coding Schemes with Vector Quantization	189
9.2.3	Lattice VQ for Image Coding	191
9.3	Fractal Image Coding.....	193
9.3.1	Mathematical Foundation.....	193
9.3.2	<i>IFS</i> -Based Fractal Image Coding.....	195
9.3.3	Other Fractal Image Coding Methods	197
9.4	Model-Based Coding	197
9.4.1	Basic Concept.....	197
9.4.2	Image Modeling	198
9.5	Summary	198
9.6	Exercises.....	198
	References	199

Section III Motion Estimation and Compression

Chapter 10 Motion Analysis and Motion Compensation

10.1	Image Sequences.....	203
10.2	Interframe Correlation.....	205
10.3	Frame Replenishment	208
10.4	Motion-Compensated Coding	209
10.5	Motion Analysis	211
10.5.1	Biological Vision Perspective.....	212
10.5.2	Computer Vision Perspective.....	212
10.5.3	Signal Processing Perspective.....	213

10.6	Motion Compensation for Image Sequence Processing	214
10.6.1	Motion-Compensated Interpolation	214
10.6.2	Motion-Compensated Enhancement	215
10.6.3	Motion-Compensated Restoration.....	217
10.6.4	Motion-Compensated Down-Conversion.....	217
10.7	Summary	217
10.8	Exercises.....	218
	References	219

Chapter 11 Block Matching

11.1	Nonoverlapped, Equally Spaced, Fixed Size, Small Rectangular Block Matching.....	221
11.2	Matching Criteria	222
11.3	Searching Procedures.....	224
11.3.1	Full Search.....	224
11.3.2	2-D Logarithm Search.....	224
11.3.3	Coarse-Fine Three-Step Search.....	226
11.3.4	Conjugate Direction Search	226
11.3.5	Subsampling in the Correlation Window.....	227
11.3.6	Multiresolution Block Matching.....	227
11.3.7	Thresholding Multiresolution Block Matching	229
11.4	Matching Accuracy	234
11.5	Limitations with Block Matching Techniques	235
11.6	New Improvements	236
11.6.1	Hierarchical Block Matching	236
11.6.2	Multigrid Block Matching.....	238
11.6.3	Predictive Motion Field Segmentation	242
11.6.4	Overlapped Block Matching	244
11.7	Summary	245
11.8	Exercises.....	247
	References	248

Chapter 12 PEL Recursive Technique

12.1	Problem Formulation	251
12.2	Descent Methods.....	252
12.2.1	First-Order Necessary Conditions.....	252
12.2.2	Second-Order Sufficient Conditions	253
12.2.3	Underlying Strategy	253
12.2.4	Convergence Speed	255
12.2.5	Steepest Descent Method	256
12.2.6	Newton-Raphson's Method	257
12.2.7	Other Methods.....	258
12.3	Netravali-Robbins Pel Recursive Algorithm	258
12.3.1	Inclusion of a Neighborhood Area.....	259
12.3.2	Interpolation.....	259
12.3.3	Simplification.....	259
12.3.4	Performance.....	260
12.4	Other Pel Recursive Algorithms	260
12.4.1	The Bergmann Algorithm (1982).....	260
12.4.2	The Bergmann Algorithm (1984).....	260
12.4.3	The Cafforio and Rocca Algorithm	261
12.4.4	The Walker and Rao Algorithm	261

12.5	Performance Comparison.....	261
12.6	Summary	262
12.7	Exercises.....	262
	References	263

Chapter 13 Optical Flow

13.1	Fundamentals	265
13.1.1	2-D Motion and Optical Flow.....	265
13.1.2	Aperture Problem	266
13.1.3	Ill-Posed Inverse Problem	267
13.1.4	Classification of Optical Flow Techniques	269
13.2	Gradient-Based Approach.....	269
13.2.1	The Horn and Schunck Method.....	269
13.2.2	Modified Horn and Schunck Method	273
13.2.3	The Lucas and Kanade Method	275
13.2.4	The Nagel Method.....	276
13.2.5	The Uras, Giroso, Verri, and Torre Method	276
13.3	Correlation-Based Approach.....	276
13.3.1	The Anandan Method.....	277
13.3.2	The Singh Method.....	278
13.3.3	The Pan, Shi, and Shu Method	281
13.4	Multiple Attributes for Conservation Information	293
13.4.1	The Weng, Ahuja, and Huang Method	294
13.4.2	The Xia and Shi Method.....	296
13.5	Summary	300
13.6	Exercises.....	301
	References	302

Chapter 14 Further Discussion and Summary on 2-D Motion Estimation

14.1	General Characterization.....	305
14.1.1	Aperture Problem	305
14.1.2	Ill-Posed Inverse Problem	305
14.1.3	Conservation Information and Neighborhood Information	306
14.1.4	Occlusion and Disocclusion.....	306
14.1.5	Rigid and Nonrigid Motion.....	307
14.2	Different Classifications.....	308
14.2.1	Deterministic Methods vs. Stochastic Methods	308
14.2.2	Spatial Domain Methods vs. Frequency Domain Methods	308
14.2.3	Region-Based Approaches vs. Gradient-Based Approaches	311
14.2.4	Forward vs. Backward Motion Estimation.....	312
14.3	Performance Comparison Among Three Major Approaches	313
14.3.1	Three Representatives	313
14.3.2	Algorithm Parameters.....	314
14.3.3	Experimental Results and Observations	314
14.4	New Trends	315
14.4.1	DCT-Based Motion Estimation.....	315
14.5	Summary	318
14.6	Exercises.....	319
	References	319

Section IV Video Compression

Chapter 15 Fundamentals of Digital Video Coding

15.1	Digital Video Representation	323
15.2	Information Theory Results (IV): Rate Distortion Function of Video Signal.....	324
15.3	Digital Video Formats.....	327
15.4	Current Status of Digital Video/Image Coding Standards.....	328
15.5	Summary	331
15.6	Exercises.....	331
	References	332

Chapter 16 Digital Video Coding Standards — MPEG-1/2 Video

16.1	Introduction	333
16.2	Features of MPEG-1/2 Video Coding	333
	16.2.1 MPEG-1 Features	334
	16.2.2 MPEG-2 Enhancements	340
16.3	MPEG-2 Video Encoding	346
	16.3.1 Introduction	346
	16.3.2 Preprocessing.....	346
	16.3.3 Motion Estimation and Motion Compensation	347
16.4	Rate Control.....	350
	16.4.1 Introduction of Rate Control.....	350
	16.4.2 Rate Control of Test Model 5 (TM5) for MPEG-2.....	350
16.5	Optimum Mode Decision.....	354
	16.5.1 Problem Formation.....	354
	16.5.2 Procedure for Obtaining the Optimal Mode.....	357
	16.5.3 Practical Solution with New Criteria for the Selection of Coding Mode.....	359
16.6	Statistical Multiplexing Operations on Multiple Program Encoding	360
	16.6.1 Background of Statistical Multiplexing Operation.....	360
	16.6.2 VBR Encoders in StatMux	362
	16.6.3 Research Topics of StatMux	363
16.7	Summary	365
16.8	Exercises.....	365
	References	366

Chapter 17 Application Issues of MPEG-1/2 Video Coding

17.1	Introduction	367
17.2	ATSC DTV Standards.....	367
	17.2.1 A Brief History.....	367
	17.2.2 Technical Overview of ATSC Systems.....	368
17.3	Transcoding with Bitstream Scaling.....	371
	17.3.1 Background.....	371
	17.3.2 Basic Principles of Bitstream Scaling	373
	17.3.3 Architectures of Bitstream Scaling	374
	17.3.4 Analysis	378
17.4	Down-Conversion Decoder.....	379
	17.4.1 Background.....	379
	17.4.2 Frequency Synthesis Down-Conversion	381

17.4.3	Low-Resolution Motion Compensation	383
17.4.4	Three-Layer Scalable Decoder.....	385
17.4.5	Summary of Down-Conversion Decoder.....	388
17.4.6	DCT-to-Spatial Transformation.....	388
17.4.7	Full-Resolution Motion Compensation in Matrix Form	389
17.5	Error Concealment.....	391
17.5.1	Background.....	391
17.5.2	Error Concealment Algorithms	392
17.5.3	Algorithm Enhancements.....	397
17.5.4	Summary of Error Concealment	400
17.6	Summary	400
17.7	Exercises.....	401
References	401

Chapter 18 MPEG-4 Video Standard: Content-Based Video Coding

18.1	Introduction	403
18.2	MPEG-4 Requirements and Functionalities	404
18.2.1	Content-Based Interactivity.....	404
18.2.2	Content-Based Efficient Compression	404
18.2.3	Universal Access	405
18.2.4	Summary of MPEG-4 Features.....	405
18.3	Technical Description of MPEG-4 Video.....	406
18.3.1	Overview of MPEG-4 Video.....	406
18.3.2	Motion Estimation and Compensation	407
18.3.3	Texture Coding	409
18.3.4	Shape Coding	413
18.3.5	Sprite Coding.....	416
18.3.6	Interlaced Video Coding.....	417
18.3.7	Wavelet-Based Texture Coding.....	417
18.3.8	Generalized Spatial and Temporal Scalability.....	418
18.3.9	Error Resilience.....	419
18.4	MPEG-4 Visual Bitstream Syntax and Semantics	420
18.5	MPEG-4 Video Verification Model	421
18.5.1	VOP-Based Encoding and Decoding Process	422
18.5.2	Video Encoder	422
18.5.3	Video Decoder	426
18.6	Summary	427
18.7	Exercises.....	427
Reference	427

Chapter 19 ITU-T Video Coding Standards H.261 and H.263

19.1	Introduction	429
19.2	H.261 Video-Coding Standard.....	429
19.2.1	Overview of H.261 Video-Coding Standard.....	429
19.2.2	Technical Detail of H.261	430
19.2.3	Syntax Description	432
19.3	H.263 Video-Coding Standard.....	433
19.3.1	Overview of H.263 Video Coding	433
19.3.2	Technical Features of H.263	434
19.4	H.263 Video-Coding Standard Version 2	439

19.4.1	Overview of H.263 Version 2	439
19.4.2	New Features of H.263 Version 2.....	439
19.5	H.263++ Video Coding and H.26L	446
19.6	Summary	447
19.7	Exercises.....	447
	References	447
Chapter 20	MPEG System — Video, Audio, and Data Multiplexing	
20.1	Introduction	449
20.2	MPEG-2 System	450
20.2.1	Major Technical Definitions in MPEG-2 System Document.....	450
20.2.2	Transport Streams.....	451
20.2.3	Transport Stream Splicing.....	456
20.2.4	Program Streams	458
20.2.5	Timing Model and Synchronization	459
20.3	MPEG-4 System	462
20.3.1	Overview and Architecture.....	462
20.3.2	Systems Decoder Model	464
20.3.3	Scene Description.....	465
20.3.4	Object Description Framework	466
20.4	Summary	466
20.5	Exercises.....	466
	References	467
Index	469